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SHUTTLE USER ANALYSIS (STUDY 2.2)

FINAL REPORT

Volume I

Executive Summary

Prepared by

Advanced Mission Analysis Directorate
Advanced Orbital Systems Division

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SHUTTLE USER ANALYSIS (STUDY 2.2) FINAL REPORT

Volume I: Executive Summary

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FOREWORD

The Shuttle User Analysis (Study 2.2) Final Report is comprised of four volumes, which are titled as follows:

Volume I	-	Executive Summary
Volume II	-	User Charge Analysis
		Part 1 - Summary
		Part 2 - The Analysis
Volume III	-	Business Risk and Value of Operations In Space (BRAVO)
		Part 1 - Summary
		Part 2 - User's Manual
		Part 3 - Workbook
		Part 4 - Computer Programs and Data Look-Up
Volume IV	-	Standardized Subsystem Modules Analysis

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Mr. William F. Moore, Missions and Payloads Office, Office of Manned Space Flight (OMSF), NASA Headquarters managed the study, coordinated the effort with NASA Headquarters personnel, and generously contributed his ideas.

The Aerospace Corporation effort on Study 2.2 was supported by the following Members of the Technical Staff:

Mission Equipment

T. Shiokari - Earth Observations
E. L. Tarca - Communications

Cost Estimating

H. G. Campbell - Space Systems
D. W. Cochran - Space Systems
O. J. Mead - Terrestrial Systems

Satellite Synthesis

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User Charge Analysis

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Economic Analysis

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Mr. E. Wetzler of ECON, Inc. also made a significant contribution to the economic analysis reported in this study.

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1. INTRODUCTION

The FY 74 Shuttle User Analysis (Study 2.2) consisted of three principal tasks:

1. STS User Charge Analysis
2. Business Risk and Value of Operations In Space (BRAVO) Analysis
3. Standardized Subsystem Module Analysis.

All three tasks were either related to or a continuation of prior year studies by The Aerospace Corporation for NASA. All three tasks were completed at Aerospace within the FY 74 effort. The results of each of these studies have proven to be directly applicable to NASA problems. Basic data needed for decision making on charge policies was derived in the User Charge Analysis. The BRAVO capability will assist NASA in bringing new space system users on board. The benefits of standardization for satellite subsystems can be routinely analyzed on a consistent basis as a part of the economic analysis of mission models at MSFC.

The STS User Charge Study is being continued within NASA Headquarters and JSC. The techniques for synthesizing spacecraft from standardized subsystem modules and for costing them has been turned over to NASA MSFC where they are being incorporated into the mission model analysis capability. MSFC, GSFC, and JSC have all shown interest in applying the capability developed in the Business Risk and Value of Operations In Space (BRAVO) task.

The User Charge Study was needed to permit NASA to initiate the process of furnishing transportation charge estimates for STS payloads to STS users. The lead time for users to plan and define new payloads or payload modifications can be long, amounting to five to seven years before flight in many cases. It has been demonstrated in other studies that the transportation charges can have a significant effect on payload plans; for instance, reduced transportation charges for payloads sharing the same flight leg can furnish incentives for multiple payload flights. Low charges for payload return will encourage payload retrieval and on-orbit payload service; thus the charge policy can provide important incentives to use the Shuttle and Spacelab. For the STS operator the incentives can help keep the STS load factors high, thus promoting efficient operation of the system. For the user the policy can encourage low-cost payload programs. Shuttle-based space operations will be supported by man and will furnish services to the payload such as power, telemetry, and checkout. This leads to the question of what charges should be made for the special services and new capabilities made available to the payload by the orbiter vehicle.

NASA is interested in contacting potential future users of space systems and responding rapidly to the questions and/or needs of these potential STS customers with minimum expenditure. The basic question may be whether to use a space system or a terrestrial system or which is the best of two or more space systems for the application. Typically, detailed users' questions and needs revolve around differences in cost, schedule, and risk when planning the expansion or improvement of their product or service by utilization of space systems. Valid answers can be provided using the proven techniques developed in the BRAVO study. The validity of most of the BRAVO techniques, with the exception of techniques for economic analysis, can be proved relatively straightforward by applying them to test cases. In order to base the economic analysis

of future systems on the best available data, a study entitled "The Proper Discount Rate Structures for Government and Private Organizations" was subcontracted to ECON, Inc. of Princeton, New Jersey. ECON studied the recent history of U. S. interest and inflation rates and methods for projection of these rates for future systems, established optimum discount rates for decision making related to project go-ahead, and developed future economic scenarios.

NASA MSFC is currently utilizing in their capture/cost analyses a satellite synthesizing methodology, developed by Aerospace, which has the capability of defining three types of spacecraft: a current design modified for reuse, low-cost expendable, and low-cost reusable. To be complete, the methodology required inclusion of the capability to define and cost satellites built up from standard modules. This capability was provided by work performed in the standardized subsystem module analysis task.

2. STUDY OBJECTIVES

The overall objective of the Shuttle User Analysis was to assist NASA in the development of their relationships with the STS user community. Specifically, the purpose of the User Charge Study was to generate alternative candidate STS flight charge approaches which will provide a basis for NASA's determination of a STS flight charge policy. The analysis used STS transportation costs furnished by NASA.

The objective of the BRAVO effort was to develop, document, and test a technical tool for rapidly answering potential space users' questions relative to the value of new or expanded space applications.

The purpose of the Standardized Subsystem Module Analysis was to provide NASA MSFC with the capability to analyze payloads constructed of standardized modules in future mission model analyses.

3. RELATIONSHIP TO OTHER STUDIES

The STS User Charge Analysis was planned and carried out based on the issues and recommendations identified in the FY 73 Payload Community Analysis sponsored by NASA as a part of Aerospace Study 2.4.

The BRAVO Study built on the extensive BRAVO effort accomplished by The Aerospace Corporation in FY 73 under Study 2.4. The capability to analyze on-orbit revisit as a mode of operation was added. Basic data for the specification of earth observation mission equipment was developed to supplement the meager information available in the previous year. The difficulties encountered in previous studies in projecting economic analyses up to 50 years into the future encouraged NASA and Aerospace to seek improvements in the basic data and techniques used for these projections. This year's BRAVO final report (Volume III) updates and revises the information in last year's report to incorporate the expansion and improvement in techniques and data bank resulting from this years effort.

The Standardized Subsystem Module Analysis was a task originally scheduled for FY 73 effort but postponed to FY 74 at the direction of NASA. It is related to the FY 73 Study 2.4 traffic analysis which resulted in the transfer of STS mission model cost and capture analysis capability from Aerospace to MSFC. However, this capability did not include the synthesis, cost, and capture of spacecraft built up of standardized modules. The FY 74 low-level study effort provided the needed capability in a form compatible with the automated traffic analysis.

The Standardized Subsystem Module analysis was also related to the task Payload Designs for Space Servicing in concurrent NASA Study 2.1, which found that standardization was applicable to at least 45 satellites in the 1973 mission model. The Study 2.2 effort made use of these standardized Aerospace module designs by modifying them as needed and applying them to the representative satellite designs defined in the analysis.

4. USER CHARGE ANALYSIS

4.1 METHOD OF APPROACH AND PRINCIPAL ASSUMPTIONS

The STS User Charge Analysis was accomplished by (1) generating criteria for evaluation of alternative flight charge approaches, (2) defining alternative flight charge approaches, (3) computing flight charges for selected missions, (4) evaluating results using the criteria generated under (1), and (5) recommending flight charge approaches to be used as a basis for the formulation of a STS user flight charge policy.

During the study seven criteria were generated. The criteria used to evaluate the alternative charge approaches are listed below.

1. Policy should recover at least $9.8M x total number of Shuttle flights in October 1973 mission model.

2. Policy should contain incentives for payload effects implementation. Return payload charge should be competitive with new payload.

3. Policy should provide incentives for high load factor operations.

4. Policy should be insensitive to mission model changes.

5. Individual user sharing a flight must be charged a fair share of total cost.

6. Charge rates must be competitive with expendable launch vehicles.

7. Policy should be simple to administer.

Initially 220 charge approaches were identified for payload transportation. When it was determined that none of the 220 initial approaches could be rated as satisfactory against each of the criteria, 40 additional charge approaches were identified.

The period for cost recovery breaks down into the following alternative approaches:

1. Recovering total transportation costs annually

2. Recovering total transportation cost for each three-year period

3. Recovering total transportation costs for each five-year period

4. Recovering total transportation costs for a ten-year period.

In the initial stages of the STS User Charge Analysis, a study was made of the current practices in the transportation industry for charging for transportation. Information was obtained from the Interstate Commerce Commission (ICC), the Air Transport Association (ATA), the International Air Transport Association (IATA), the Military Airlift Command (MAC), the Civil Aeronautics Board (CAB), and several airlines with scheduled cargo transportation services or chartered service.

A number of parameters were considered in the study as potential add-on charges for payload transportation. Among these were:

1. Special payload integration charges

2. Ancillary equipment charges

3. Charges for STS flight crew in excess of normal complement

4. Orbiter occupancy time

5. Priority flights

6. Piggyback payloads.

Special studies were requested by NASA to analyze the potential effects of changes in transportation costs on breakeven costs for foreign domestic communication satellite systems, U. S. domestic communication satellite systems, and traffic management systems. Studies were made on a quick-response basis to attempt to define the threshhold costs for international communication systems vs submarine cables and for U. S. domestic communication systems vs long line microwave systems. The approach for domestic communications was to estimate typical intercity communication costs for links internal to the United States. This was done using BRAVO techniques for satellite systems and their terrestrial counterparts, each handling the same communication demand. The breakeven costs between satellite systems and terrestrial systems are a function of distance and traffic level. Intercity links with approximately the same level of traffic were selected for comparison so that the breakeven distance is a function of transportation costs.

Figure 4-1 displays the launch cost estimated for typical breakeven points. Thus a launch cost lower than the breakeven point would allow the Domsat B system to be competitive with the terrestrial communications network. Also shown is the sensitivity of the breakeven distance between cities to the launch cost for Los Angeles to Dallas long-distance communications traffic. These data indicate that U. S. Domsat, launched for $10M per satellite, would be competitive for the Los Angeles/Chicago or Los Angeles/Dallas communications traffic. However, to capture the shorter haul (e.g., Los Angeles/Phoenix) traffic, the launch cost per satellite would have to drop below $7M.

4.2 BASIC DATA GENERATED AND SIGNIFICANT RESULTS

For 80 of the cases (or STS user charge approaches as they are sometimes referred to), the charges were computed and evaluated against the seven criteria for the flights scheduled in 1984 in the October 1973

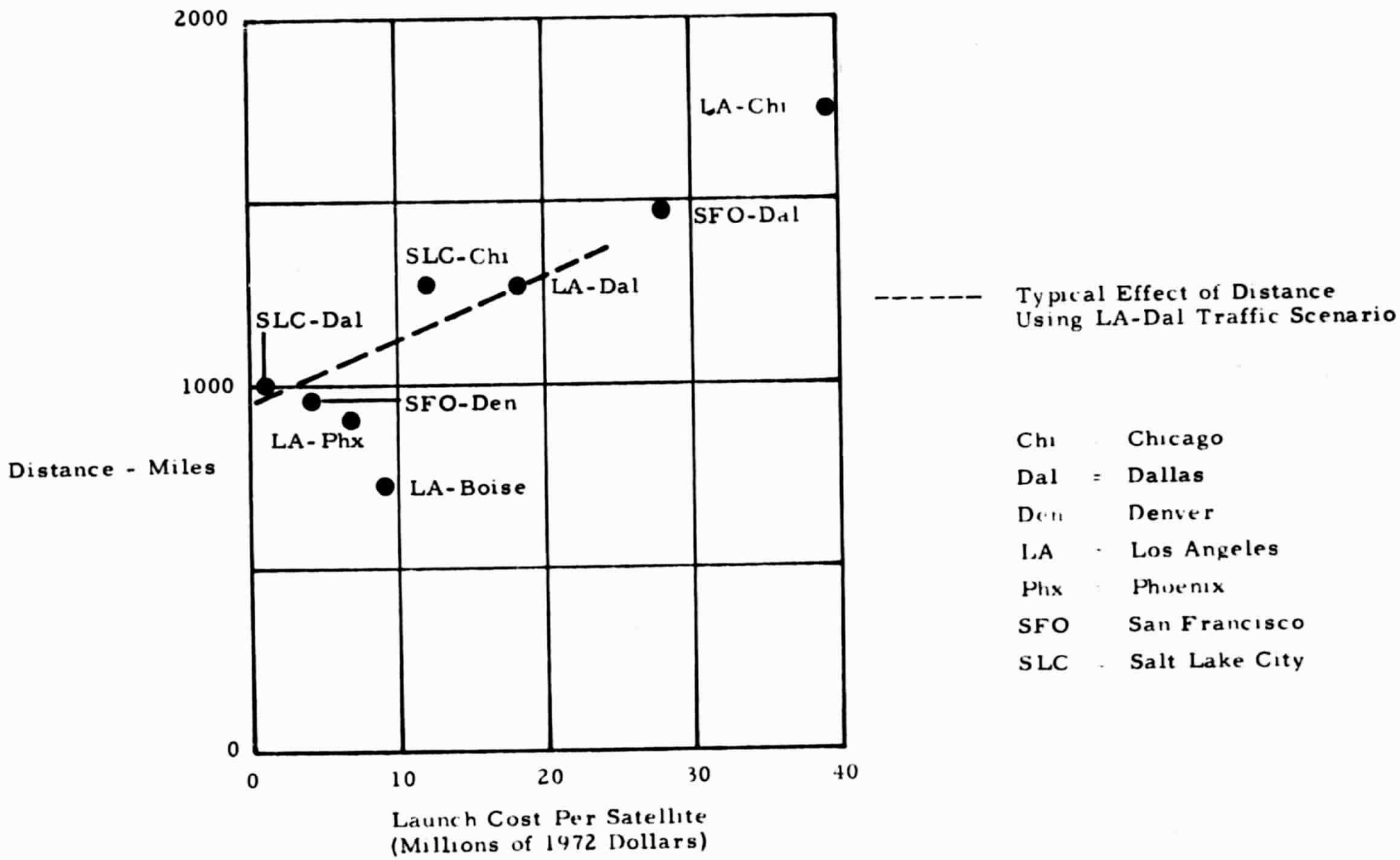

Figure 4-1. Equal Revenue Required Points Between Shuttle-Launched Domsat B Communications and Terrestrial Communications

NASA mission model. DOD flights were excluded. Eight of the charge approaches were analyzed using all 12 years of STS payload flights from this same mission model. In addition, these eight charge approaches were analyzed and evaluated using the traffic data in the NASA 1972 mission model.

The evaluation of charge approaches resulted in the recommendation to NASA that they consider one as a primary candidate and a second charge approach as an alternate. The primary candidate is called composite cargo charge approach and provides for a minimum charge and a variable charge for each payload transported, with incentives for sharing and return. The rates charged can be varied to suit the projected STS traffic. In the backup charge approach, the payload weight/size class approach, payload charges to each of the high-traffic orbits were computed for each payload class (small, medium, large, and extra large).

It was found that commercial cargo transportation charge policies have historically evolved from carrier-user negotiations with cognizant agency approval. There is general acceptance of the principle that revenue is based on cost plus a reasonable return, with charges for transportation being based on weight of the cargo and distance transported. Many carriers prefer weight over volume charges because weight is rapidly and easily measured; however, some carriers are concerned about the volume limitations on their cargo in carrying vehicles and make extensive use of either a minimum charge or charges by weight or volume, depending on which is larger. The best example of this is in air cargo.

Commercial cargo charge policies and practices which have some degree of applicability to STS are:

1. Revenue based on cost plus a reasonable return
2. Charges by cargo weight
3. The cube rule modified to be applicable to the STS
4. Minimum charges, again modified to be applicable to the STS
5. Rate charges for special commodities or classes of cargo
6. Fixed rates analogous to those used by IATA
7. An industrial fund approach similar to that used by MAC
8. Incentives for high load factor including reduced costs for larger-weight payloads and incentives for return leg (inbound) payload traffic similar to the MAC incentive
9. The policy of limiting liability of the carrier with respect to the cargo carrier.

5. BUSINESS RISK AND VALUE OF OPERATIONS IN SPACE (BRAVO)

5.1 METHOD OF APPROACH AND PRINCIPLE ASSUMPTIONS

The BRAVO tool considers the function of the system, system risk, and system cost in making comparisons between ground systems and space systems, or comparisons between two or more different space systems. The approach taken in developing the tool is that a competing ground system and a space system should have equal capability to perform the function or service desired by the potential user if they are to be compared. The risks also are made as nearly equal as possible between the space system and the ground system to be compared. One way this is accomplished is to configure the space system to have a risk equal to the ground system or the user's specified risk (usually system outage allowance). With the STS as the space system launch vehicle, the risk associated with the system varies with satellite logistics (e.g., frequency of launch), or satellite reliability, or both. With the STS, the satellite development risk also can be varied with changes in the development approach and expenditure, although the latter is not as significant as the outage problem[(1)].

When the capability and risk are equal, the system costs can be compared using economic analysis techniques.

The approach for development of BRAVO techniques includes testing the analytical tool against other studies on the same user needs. Reasonable agreement can be expected between two studies utilizing different data banks and techniques if the inputs and ground rules are the same.

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(1) Development programs have been funded historically at a level consistent with their historical operating success. It is the historical operating success which is being represented in this analysis.

Ground rules for the BRAVO procedures include the following:

1. The lowest cost approach for each system is utilized. In order to accomplish this, the alternative system approaches are configured, costed, and compared as a part of the routine procedure. For instance, in a specific application, if the analyst is not sure whether the lowest cost approach would include spare satellites on orbit or not, both alternatives would be analyzed and the lowest cost approach meeting system requirements would be chosen.

2. Unless the potential user specifies that a dedicated system is needed, the analysis considers shared system capability as well as dedicated systems for the application. Again, the choice between the two is made on the basis of minimum cost.

3. It is assumed that the space systems to be analyzed will be operating in the space transportation system era, most likely 1985 or later. Several potential advantages for space systems are foreseen for the STS era:

   a. Space system risks will be decreasing with the STS capability

   b. Space system buy-in costs may be decreasing

   c. Space system applications activity level has a potential for increasing

   d. Space system development lead times have a potential for decreasing.

4. It is assumed that the user will accept payload designs which follow design rules and guidelines for STS payloads (e.g., from Reference 1: "Satellites developed for operational systems shall be reusable, operate in a reusable mode, and be short in length for multiple launch capability"). Design rules for STS payloads may be found in References 1, 2, and 3 and in Section 4.3, Part 2, Volume III of this report.

5. It is assumed in the economic analysis that no major surprises occur, such as large-scale warfare or a large-scale depression in the economy.

The BRAVO approach has the unique advantage of bringing the user closer to the analysis. User inputs are used directly in setting up the analysis. The output of the analysis is primarily cost information and data which can be understood by most potential space users. Therefore, little understanding of space systems per se is required for the user to understand the study results. When the potential user establishes the demand for a function or service to be performed, it is presumed to be described in a manner reflecting his own assessments of the market for his particular products or services. Therefore, the results of the analysis fit directly into the potential user's planning and thinking. It is also quite possible that the techniques developed for the BRAVO tool could be employed by a user directly to do an independent analysis.

5.2 BASIC DATA GENERATED AND SIGNIFICANT RESULTS

The end result of a BRAVO analysis is illustrated in Figure 5-1. The economic advantages or disadvantages can be measured in many ways at the end of an analysis. The cumulative cash flow over the period of installing and operating a particular system to meet an expected demand measures the return to the user on his investment in terms of cumulative cash and also shows the peak deficit cash flow encountered. Cash flow can be presented in either constant dollars or current (inflated) dollars. Both are usually of interest.

In FY 74 the BRAVO capability for analysis of earth observations was expanded. The techniques for mission equipment selection in the space system analyses and the terrestrial system analyses were improved in the earth observation area. The capability to analyze on-orbit service was added to BRAVO. Major changes were made to satellite synthesis, STS accommodation and traffic analysis, and space system risk and

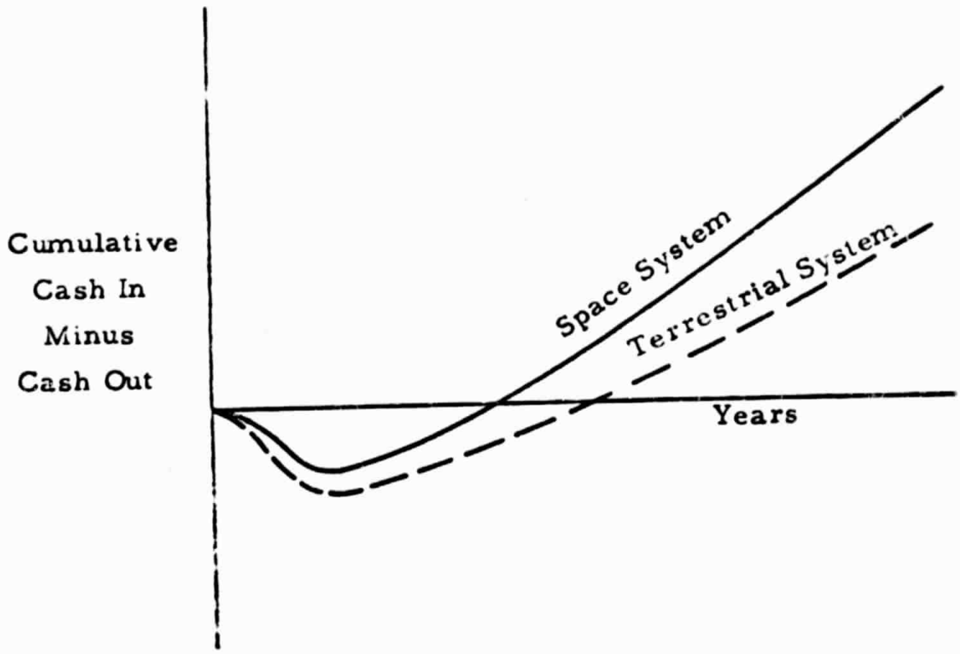

Figure 5-1. Cash Flow at Equal Demand, Equal Revenue, and Equal Risk

optimization analysis in the space system analysis in order to analyze satellite design and operation in an on-orbit service mode. The cost-effectiveness analysis techniques were improved. Economic scenarios and predictions for long-term projects have been put on a firm basis, utilizing work accomplished on a subcontract to ECON, Inc. The techniques for economic analysis were computerized.

The BRAVO tool capability is sufficient to analyze most normal space systems and comparable ground systems which fit the limitations (automated, application-type space systems, etc.) when the user specifies the mission equipment. The BRAVO capability developed to date also includes synthesis of channel-type communications system mission equipment where the user has not specified the mission equipment. The mission equipment synthesis is accomplished with BRAVO procedures using the potential user needs as requirements. The BRAVO capability also includes the data for making estimates on earth observation satellite mission equipment characteristics appropriate for systems in the 1980s.

The BRAVO tool has been tested by (1) applying it to future international communications satellites and comparing analyses with those of the Comsat Corporation, (2) applying it to a solar cell power satellite of advanced design and comparing results with similar studies by A. D. Little and associated contractors. Agreement was good in both cases. The results of two other test cases will be known when the contractor studies are completed and the studies compared. These latter two test cases are (1) running a BRAVO analysis on the same problem being considered in the TRW study on an STS-launched defense communication satellite system, DSCS-II, and (2) running a BRAVO analysis on the earth observation satellite system being defined for GSFC by three contractors.

6. STANDARDIZED SUBSYSTEM MODULE STUDY

6.1 METHOD OF APPROACH AND PRINCIPLE ASSUMPTIONS

The plan for the study was to use an inventory of standardized module designs obtained from Study 2.1[(1)]. The characteristics of these modules were reviewed for the purpose of reducing the number of different modules and increasing the number of applications of each module to obtain cost reduction. The number of standardized modules was reduced for each of the following subsystems: (1) attitude control, (2) electrical power, and (3) telemetry, tracking and command. In order to determine the applicability of the modules to new satellites, the driving (key) performance capability(s) of each module was identified. Documentation describing four reference satellites was reviewed to obtain satellite descriptions, program characteristics, and subsystem design parameters used with the key capabilities of the modules to synthesize a standardized configuration. The four reference satellites were the Synchronous Equatorial Orbiter (SEO), the Orbiting Astronomical Observatory (OAO), the Earth Observatory Satellite (EOS), and the Domestic Communications Satellite (COM). The baselines for the reference satellites were the same baselines which were used in the Lockheed Missiles and Space Company's Low Cost Satellite Study. The standardized referenced satellites were then used in conjunction with the baseline satellites to obtain subsystem weight growth factors.

The standardized subsystem module spacecraft descriptions were then used to estimate standardized subsystem and spacecraft costs. Allowances for the sharing of subsystem DDT&E costs between users and a production rate effect applied to unit costs resulting from multiple use

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(1) Study 2.1, "Operations Analysis," examined space servicing of modularized spacecraft. Aerospace report ATR-74(7341)-3, "Operations Analysis (Study 2.1) Payload Designs for Space Servicing," dated 30 June 1974, describes the payload design activity associated with this servicing study.

were included. These cost estimates were then used with cost estimates of the baseline configuration to develop cost factors. These cost and weight growth factors were put into a form so that they could be applied routinely to payloads configured from standardized subsystem modules as a part of the automated capture/cost analysis techniques at MSFC.

6.2 BASIC DATA GENERATED AND SIGNIFICANT RESULTS

The results of this study are additions to the satellite weight estimating computer program and payload cost estimating computer program which provide this capability. The computer program modifications are described in Volume IV of this final report.

The satellite synthesis method uses weight growth factors. The growth factor is a function of the baseline subsystem weight providing a larger growth factor for small subsystem weights. The factors are applicable to baseline satellite dry weights from 317 kg (700 lb) to 29,480 kg (65,000 lb). The factors are applicable to 2-axis or 3-axis stabilized spacecraft and not recommended for spin stabilized satellites. The standardized satellite design approach applies to satellites maintainable on orbit or retrieved for ground maintenance and supported by the STS system. The design concepts are general, not tied to specific packaging or orbital maintenance concepts.

Standardized satellite cost reductions over baseline satellite costs are significant. Standardized satellite cost changes relative to current design reusable spacecraft depend on the satellite studied and, on the average, show a modest savings.

7. STUDY LIMITATIONS

In the BRAVO study, it was originally planned that the number of applications for BRAVO during the year would be larger than the three test cases. Attempts to coordinate potential application studies with NASA project offices, although valuable to the BRAVO effort, did not produce agreement on the additional new applications. These additional applications, such as forestry, oceanography, and manufacturing on orbit, were eliminated from the effort.

For the User Charge Analysis, no serious study limitations were encountered. The study considered typical cost per flight as furnished by NASA. It is assumed that in the follow-on in-house work NASA will explore the effects of potential variations in STS costs per flight.

For the Standardized Subsystem Module Analysis, the resources available limited the study to the development of representative satellite buildups from standardized modules. The alternate approach would develop an automated methodology for building up satellites from a standardized module inventory. This would be a preferable method, however, the effort required exceeded the resources available for this approach.

8. IMPLICATIONS FOR RESEARCH

In NASA's drive for lower cost space activities, the BRAVO and Standardized Subsystem Module analyses confirmed again the desirability of pursuing standardization, on-orbit revisit capability and, in the case of dual spin satellite designs, ground refurbishment. While it would take additional study to define specific implications for research, it was found that efficient and reliable techniques and equipment for satellite retrieval and repair will be needed.

9. SUGGESTED ADDITIONAL EFFORT

It is recommended that the BRAVO capability be transferred to NASA for use in analysis of potential new space systems. The group responsible for this work should be independent enough to accomplish studies which will be credible to the potential users outside of the NASA organization.

It is recommended that the User Charge Analysis effort continuing at NASA in house be based on the findings of Study 2.2. The study needs to be expanded to include consideration of (1) the amount to be recovered by transportation charges, (2) charges for such extras as piggy-back payloads, extra flight crew, Shuttle occupancy time in excess of normal, etc., and (3) policy relative to transportation charges for non-payload weight chargeable to the user such as orbiter RCS propellant.

A finding which generally appears from applying BRAVO to a specific user problem, clearly demonstrates the value of extended satellite life through redundancy. This "value" comes from reduced transportation costs and reduced spacecraft hardware refurbishment costs. It is recommended that NASA study methods for implementing extended spacecraft life through redundancy within the NASA project offices and standard equipment under development.

10. REFERENCES

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